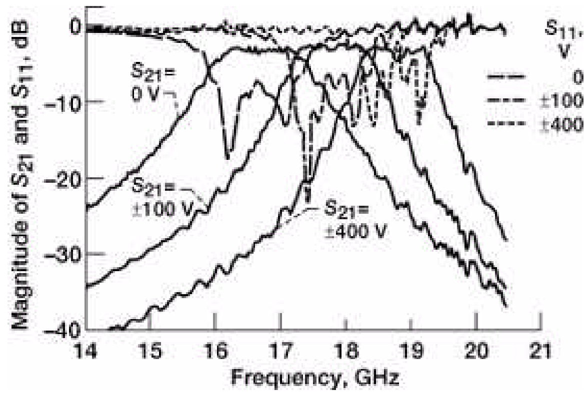
Thin-Film Ferroelectric Tunable Microwave Devices Being Developed

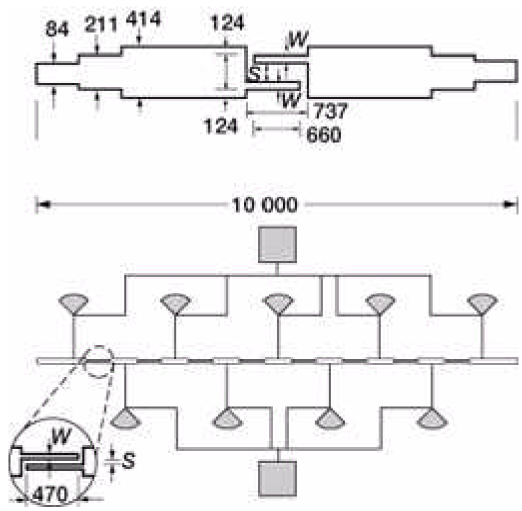
Electronically tunable microwave components have become the subject of intense research efforts in recent years. Many new communications systems would greatly benefit from these components. For example, planned low Earth orbiting satellite networks have a need for electronically scanned antennas. Thin ferroelectric films are one of the major technologies competing to fill these applications. When a direct-current (dc) voltage is applied to ferroelectric film, the dielectric constant of the film can be decreased by nearly an order of magnitude, changing the high-frequency wavelength in the microwave device. Recent advances in film growth have demonstrated high-quality ferroelectric thin films. This technology may allow microwave devices that have very low power and are compact, lightweight, simple, robust, planar, voltage tunable, and affordable.

The NASA Lewis Research Center has been designing, fabricating, and testing proof-of-concept tunable microwave devices. This work, which is being done in-house with funding from the Lewis Director's Discretionary Fund, is focusing on introducing better microwave designs to utilize these materials. We have demonstrated Ku- and K-band phase shifters, tunable local oscillators, tunable filters, and tunable diplexers. Many of our devices employ $SrTiO_3$ as the ferroelectric. Although it is one of the more tunable and easily grown ferroelectrics, $SrTiO_3$ must be used at cryogenic temperatures, usually below 100 K. At these temperatures, we frequently use high-temperature superconducting thin films of $YBa_2Cu_3O_{7-\delta}$ to carry the microwave signals. However, much of our recent work has concentrated on inserting room-temperature ferroelectric thin films, such as $Ba_xSr_{1-x}TiO_3$ into these devices. The $Ba_xSr_{1-x}TiO_3$ films are used in conjuction with normal metal conductors, such as gold.

The first example of ferroelectric-based components is the tunable filter, which has a compact, planar design. The metallic layer consists of a thin $YBa_2Cu_3O_{7-\delta}$ superconducting film. A 300-nm-thick $SrTiO_3$ ferroelectric film lies below the metallic layer on a $LaAlO_3$ dielectric substrate. The *S*-parameter transmission and reflection measurements in the following graph indicate that filter's center frequency shifted from 16.5 GHz at no bias, to 18.8 GHz at ±400 V bias, showing a tuning range of 12 percent at 30 K. The passband losses are relatively flat, and the minimum embedded insertion loss is 1.5 dB. These results demonstrate the feasibility of using ferroelectric thin-film planar microstrip filters at Ku-band frequencies. Recent activities include fabricating and testing these tunable filters with ambient temperature ferroelectrics (e.g., $Ba_xSr_{1-x}TiO_3$).

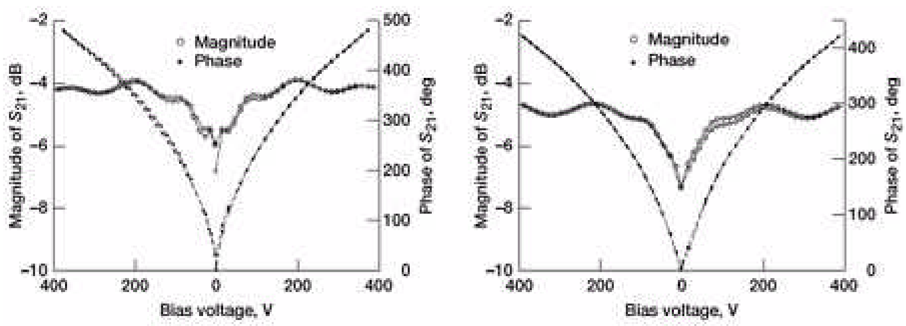


Bias dependence of transmission signal, S_{21}, and reflectance signal, S_{11},> measurements for a tunable bandpass filter at 30 K.



Schematic of two coupled microstrip phase shifters. All dimensions are in micrometers. Top: 25-W single-element phase shifter; S = 12.7 mm, W = 76.2 mm. Bottom: 50-W eight-element phase shifter; S = 7.2 mm, W = 25 mm.

Extensive work has gone into developing these novel ferroelectric coupled microstrip phase shifters, which were invented at Lewis. Two configurations of these phase shifters are given in the following schematic. The ferroelectric thin film again lies below the metallic circuit on a crystal substrate. Direct-current bias is applied between the coupled microstrips, strongly affecting the dielectric constant of the ferroelectric in the gap and causing a microwave phase shift. Larger phase shifts are obtained by placing several of these coupled microstrip sections in series. At cryogenic temperatures, these devices have shown nearly 500° of phase shift with figures of merit of 80° of phase shift per 1 dB of loss. These results are shown in the following graphs for a $YBa_2Cu_3O_{7-\delta}/SrTiO_3/LaAlO_3$ multilayer structure. Ongoing efforts are extending and modifying these designs to different ferroelectric films, which are being doped to reduce losses, and to different dielectric substrates.



Phase shifts of 50-W, eight-element, $YBa_2Cu_3O_{7\text{-}d}$ (0.35 mm)/$SrTiO_3$ (1.0 mm)/$LaAlO_3$ (254 mm) coupled microstrip phase shifter. Left: Temperature, 40 K; frequency, 16 GHz. Right: Temperature, 77 K; frequency, 16 GHz.

In addition, proof-of-concept tunable local oscillators have been assembled from thin-film ferroelectric ring resonators combined with gallium arsenide PHEMT’s (pseudomorphic high electron mobility transistors). These devices have shown apparent unloaded quality factors up to 15 000 and frequency tuning ranges of 2 GHz in the Ku-band. Also, two tunable filters have been linked to form a tunable diplexer operating at the Ku- and K-bands. The tunable local oscillator and tunable diplexer are intended to be integrated into a discriminator-locked tunable oscillator currently under development at Lewis.

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